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FRICTION-WELDING DEVICE

The present invention relates to a friction-welding device for the integral joining of components according to the generic part of Claim 1.

Friction-welding devices are known in widely differing designs. One distinguishing criterion is the utilized kinematical principle. In the case at hand, devices are involved in which one of two components to be joined is held statically, the other is moved in an oscillating manner, i.e., periodically moved back and forth, and is pressed against the static component in the process. The periodic movement occurs parallel to the provided welding surfaces and is generated by a so-called oscillator. The pressing occurs perpendicular to the welding surfaces with the aid of a suitable compression device. Due to the high compression and friction forces, the usually smaller, moved component is retained in a sturdy cartridge that leaves only the welding zone accessible in most cases. The oscillatory movement may be implemented on a straight and/or curved path, for instance on a portion of a circular arc. In the straight-line variant, the designation "linear friction welding", abbreviated LFW, is often used. In view of the high dynamic stresses, all elements of a friction-welding device must be designed as especially robust and dimensionally stable elements which are free from play, which applies especially when larger components made of high-strength metals are welded. Also important are precise, reproducible and variable friction and compression movements with high positioning accuracy at the end of the dynamic friction process. All of these criteria, after years of development, have had the result that mechanical and hydraulic variants as well as combinations of the two have become accepted for the direct generation of the required forces and

motions. It is understood that the corresponding drives also include electromotors, electronic open-loop and closed-loop controls, i.e., electrical and electronic elements.

The European patent 0 513 669 B1 protects a friction-welding method for the blading of a blade carrier for turbo engines together with the required device and device elements. The actual implementation of this friction-welding device operates with the aid of an electromotorically driven, mechanical oscillator according to an eccentric principle, as well as with an electro-hydraulic, pressurized hydraulic compression device.

In mechanical oscillators the maximum movement frequency is limited to values below 100 Hertz (Hz). In hydraulic oscillators the maximum frequency is above 100 Hz but still below 150 Hz. According to the equation power - force x velocity, the friction power is proportional to the friction force, the movement amplitude and the movement frequency. The friction force results from the normal force and the coefficient of friction. At a predefined amplitude, predefined frequency (cf. above maximum values) and predefined coefficient of friction, the friction power can be increased or influenced only via the normal force/pressure force. At a predefined friction power, the relative low frequencies of the mechanical and hydraulic oscillators result in correspondingly high contact pressures that have to be generated by the compression device. High forces require mechanically especially robust and massive, i.e., heavy, components for the friction-welding device.

In view of the known approaches and their disadvantages, it is the objective of the present invention to provide a friction-welding device for the integral joining of components having periodic movement of one component, which yields geometrically

more precise integral components as a result of more precise and better reproducible function, and which allows the manufacture of more filigreed constructions due to higher movement frequencies and lower friction power, lighter and smaller, space-saving device elements being utilizable in the welding area.

This object is attained by the features characterized in Claim 1, in connection with the generic features in its first part. According to the present invention, the oscillator includes two or a higher, even number of piezoactuators, which are arranged in pairs at least approximately on a line of application. The piezoactuators exert compressive forces from opposite sides on the cartridge having the moved component, so that a defined prestressing is able to be realized, and the periodic friction movement occurs practically without play. Via the electric voltage control/regulation of the piezoactuators with the possibility of acting on each actuator individually, it is possible to select the mechanical prestressing of the cartridge, the movement frequency, the movement amplitude, and the zero position of the movement, including the final position at the end of the welding operation, very precisely and in a reproducible manner. The requirement of complicated refinishing to compensate for geometrical inaccuracies of the welded unit, for instance by NC milling, is thereby considerably reduced or eliminated. Due to the lower frictional forces, a smaller and lighter cartridge etc., it is also possible to use friction welding to produce and repair filigreed, mechanically sensitive blisks (<u>bl</u>aded d<u>isks</u>) with narrowly positioned blades. In the process, the hubs/disks of the rotors are able to be optimally adapted to the operating loads and for the most part be fully finished, so that they will no longer have to be provided in oversize or with considerable allowances in view of the

friction-welding loads, such allowances having to be removed again later on.

The dependent claims characterize preferred developments of the friction-welding device according to the main claim.

Hereinafter, the present invention is explained in greater detail with reference to the figure. In a highly simplified representation that is not to scale, the figures show:

Fig. 1	An axial detail of a blade carrier having a blade to be affixed thereon;
Fig. 2	The detail according to Figure 1, supplemented by a friction-welding device;
Fig. 3	A radial detail of the blade carrier, the blade and the friction-welding device according to Figure 2;
Fig. 4	A tangential detail of a blade carrier, a blade and a friction-welding device having four pairs of actuators;
Fig. 5	A detail of a piezoactuator having a flat spring arrangement; and
Fig. 6	An arrangement of piezo elements.

Figure 1, in an axial view, shows a portion of a blade carrier 4 intended for a rotor of a turbo engine on which a blade 3 is to be affixed by friction welding. The oscillating friction movement is to occur transversely to the longitudinal center axis of blade carrier 4, which is symbolized by a horizontal double arrow for friction force Fr. Only blade 3 is moved in the process; blade carrier 4 is held statically. Welding surfaces 5, 6 are pressed against each other by a compression force Fs directed perpendicular to the surfaces, compression force Fs being introduced into welding zone 7 via moved blade 3. The force arrow pointing toward the blade tip from above is irrelevant for the actual type of force application into

blade 3. To be preferred, certainly, is a force application producing an even loading, if possible, of a large portion of the blade surface by a frictionally engaged or a keyed connection.

In addition to components 3, 4 to be friction-welded, Figure 2 shows a friction-welding device 1 according to the present invention. For better understanding, Figure 3 should be consulted as well. To transmit the considerable forces, blade 3 is virtually completely encased in a mechanically sturdy cartridge 11, preferably made of steel or hard metal, the inner contour of cartridge 11 being adapted to the blade contour in the best-possible manner. Cartridge 11 is made up of two or more parts which are screwed together and have separating lines that are adapted to the blade geometry. In addition to cartridge 11, oscillator 8, which generates a defined, periodic friction movement parallel to welding surfaces 5, 6, and compression device 10, which produces a defined compression force and feed movement, are essential elements of friction-welding device 1. In the present example, both oscillator 8 and compression device 10 operate according to the piezoelectrical principle, i.e., on the basis of linear deformation of the piezoelements caused by electric direct voltage. Shown in Figure 1 are two horizontal piezoactuators 12, 13 of oscillator 8, which lie on a line of application and engage with cartridge 11 from the left and right, as well as a piezoactuator 16 of compression device 10, which engages with cartridge 11 vertically from above. The force-transmission points between the piezoactuators and cartridge 11 will usually have one or more degrees of freedom, depending on the relative movement, for instance for translatory displacements and/or swiveling motions. Slide bearings and/or roller bearings may be used in this context. In the case at hand, for instance, a pivoting joint with a degree of freedom may be arranged between piezoactuator 16 and

cartridge 11. The implementation of the force-transmission points is part of the conventional expert knowledge and not a direct subject of the present invention. The drawn-in double arrows indicate a synchronous, equidirectional motion of piezoactuators 12 and 13.

The principle of the present invention becomes even more apparent through Figure 3. This radial detail of blade carrier 4 and blade 3 shows the blade profile encased by cartridge 11 and the separating lines of cartridge 11 adapted thereto. Longitudinal center axis X of the blade carrier, i.e., its later axis of rotation, runs vertically in this view. It is understood that, in a new blading of blade carrier 4, a multitude of blades 3 positioned in close proximity to one another must be affixed at the circumference, only one of which is shown here for reasons of clarity. As a result, cartridge 11 must be designed such that there is room for it between already installed blades. This is the explanation for the offset form of the cartridge shown in simplified form. In the case at hand, oscillator 8 has four piezoactuators 12 to 15, which are arranged in pairs on a line of application and are situated transversely to longitudinal center axis X. It should be noted that the piezoactuators may have lengths of several meters due to the required oscillation amplitudes of several millimeters, a multitude of piezoelements being geometrically connected in series, i.e., are arranged one after the other. Therefore, it is advantageous to arrange the long piezoactuators 12 to 15 in the manner shown, in pairs, axially in front and behind the bladed, or to be bladed, blade carrier 4. It should be noted that friction-welding device 1 may be used both for the production of new parts and for repair purposes (repair), i.e., for the replacement of individual or several blades. The two front piezoactuators 12, 13 are synchronously controlled in such a manner that they always rest against

cartridge 11 under compressive stress. The same applies to the two rear piezoactuators 14 and 15. Also, it will most likely be the case that the front actuator pair is operated at the same frequency as the rear actuator pair. Given an in-phase condition and identical amplitude of the front and rear actuator pair, blade 3 executes a straight oscillating motion. However, there are also the options of operating an actuator pair at different amplitude and/or with a phase shift relative to the other, yet at the same frequency. For blade 3 that means that combinations of translatory motions and swiveling motions or pure swiveling motions about variable pivotal points are possible. In this context, reference is made to the straight and the curved double arrow above blade 3. This requires a correspondingly flexible connection of piezoactuators 12 to 15 to cartridge 11. Using locally different forms of movement and different amplitudes, the introduced friction energy may be varied across the welding surfaces, for instance, less friction energy in thin blade regions than in thick regions, so that an even temperature distribution and, ultimately, a better welding result may be achieved.

Figure 4 shows a detail of blade carrier 4 with blade 3 in the circumferential direction/tangential direction, longitudinal center axis X of blade carrier 4 extending vertically and to the right next to the actual representation. Friction-welding device 2 utilized here differs from the above-described friction-welding device 1 in that its oscillator 9 includes four pairs of piezoactuators, i.e., eight piezoactuators, the representation showing only the four piezoactuators 17 to 20, which are arranged in front of cartridge 11 in the view. Relative to longitudinal center axis X, the effective plane of piezoactuators 17, 18 lies at a greater radial height H2 than the effective plane of piezoactuators 19, 20, which lies at radial height H1. During friction-welding experiments it has

become apparent that blades exhibit a slight, undesired tilt in the circumferential direction after welding despite precise radial alignment in the cartridge. Utilizing the illustrated, height-offset actuator pairs makes it possible to adjust a selective small, oppositely-directed tilt of cartridge 11 and blade 3 in the circumferential direction during the welding operation, for instance by geometric shifting of the zero point of the higher actuator pairs relative to the lower actuator pairs, so that the exact desired blade orientation results at the end of the welding operation. Compression device 10 having piezoactuator 16 may have the same design as in the previous figures.

The movement amplitudes of piezoactuators relative to the actuator length are in the per mill range. To reduce the actuator lengths at predefined amplitudes, the actuator amplitudes may be mechanically increased, different gear mechanisms being possible. To this end, Figure 5 shows a flat-spring arrangement 22 by way of example. Two or more flat springs are fixedly clamped into a static base 25 at one end. The other ends of the flat springs are embedded in a displaceable part 24. A pull/pressure element connected to a piezoactuator 21 engages with the flat springs in the region between base 25 and part 24. By elastic deformation of the flat springs, part 24 is moved at a greater amplitude and the same frequency in relation to the pull/pressure element. By moving the pull/pressure element to base 25, it is possible to increase the movement amplitude of part 24 while reducing the force exerted by part 24. The movement of part 24 is not exactly linear here since a certain swiveling motion is superposed. The kinematics closely resemble a guidance in the form of a parallelogram.

As already mentioned, piezoactuators having amplitudes in the millimeter range have a multitude of piezoelements in a

geometrical series connection. It is quite possible that several hundred such piezoelements are present. Since conventional piezoelements are restricted in cross-section, for instance to the size of a coin, for the generation of great forces it may be required that a plurality of "columns" of piezoelements connected in series must be arranged in parallel and be combined in a, for instance, tubular actuator. Figure 6, in highly simplified form, shows two "columns" arranged in parallel on a statical base 26. The two columns lead to a displaceable yoke 27 which has the same movement amplitude as each of the columns, at twice the compressive force compared to a single column. Of course, more than two collimated "columns" may be combined in one actuator. The geometrical/constructive serial or parallel connection must not be confused with the electrical circuit of the piezoelements where electrical serial and parallel connections are used as well, the latter especially for the purpose of limiting voltages.